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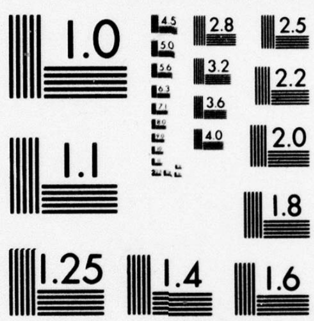

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A PHOTOPLASTIC STUDY OF RESIDUAL STRESS IN AN OVERLOADED BREECH RING

Y. F. Cheng

November 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

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A two-dimensional model of the meridian section of a breech ring was made of a photoplastic material which had been calibrated optically and mechanically. The maximum fillet stress was determined for an elastic load as well as an elastoplastic load. Residual stress resulting from complete unloading was calculated by subtractive superposition of elastic and plastic solutions. An elastic process is assumed during unloading. Transition from model to prototype was discussed.

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ACKNOWLEDGEMENT

Charles Cobb's participation in the experimental phase of this investigation is hereby acknowledged.

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INTRODUCTION

In guns with a sliding breechblock mechanism, breech ring failures have been observed originating from the lower fillet in the vicinity of the contact region. This observation indicates that high tensile stress produced by stress concentration at the fillet was responsible for the failure. One can reduce the stress concentration by changing the fillet geometry.[1] Alternately, the breech ring can be overloaded into the plastic range to produce beneficial residual stress as long as future loadings are within the linearly elastic behavior of the material.

This report describes a photoplastic investigation on residual stress at the lower fillet in an overloaded breech ring after unloading. The principles of photoplasticity are given, experiments and results are shown, and the transition of photoplastic results from model to prototype is considered.

PRINCIPLES OF PHOTOPLASTICITY

The photoelasticity method is based on the linear stress optic law. Specifically, at any point in a model the fringe order is proportional to the principal stress difference and the isoclinic parameter gives the directions of the principal stresses. From this

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[1]Cheng, Y. F., "On Maximum Fillet Stresses in Breech Ring," Watervliet Arsenal Technical Report WVT-7255, October 1972.

information, the state of stress can be determined. The discovery of the non-linear stress-optic[2,3] extends the photoelastic method into the plastic range.

Solutions of problems in stress distribution, whether elastic or plastic, must satisfy three conditions: (a) equilibrium, (b) compatibility, and (c) boundary values. In the plane elastic state of stress, the conditions which must be satisfied in the transition from model to prototype are those of similarity of geometry and loading. In order to make the transition involves plastic flow; at least three more conditions must be met: (a) the stress-strain curves of the materials of model and prototype must have the same shape, (b) the law of yielding must be the same for both materials, and (c) Poisson's ratio in the plastic state must be the same for both materials.

POLYCARBONATE AS MODEL MATERIAL

Polycarbonate resin (ester of carbonic acid and bisphenol A) was first suggested in 1962[4] for use as photoplastic model material. It behaves as a ductile material and has good transparency under both elastic and plastic states.[4] It has a Poisson's ratio of 0.38 in the

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[2] Frocht, M. M. and Thomson, R. A., "Studies in Photoplasticity," Proceedings 3rd US National Congress Applied Mechanics, pp. 533-540, 1958.

[3] Frocht, M. M. and Cheng, Y. F., "An Experimental Study of the Laws of Double Refraction in the Plastic State in Cellulose Nitrate - Foundations for Three-Dimensional Photoplasticity," Proceedings International Symposium of Photoelasticity, pp. 195-216, 1961.

[4] Ito, K., "New Model Materials for Photoelasticity and Photoplasticity," EXPERIMENTAL MECHANICS, Vol. 2, No. 12, pp. 373-376, December 1962.

elastic state and a limiting value of 0.5 in the plastic state.[5] It shows both optical and mechanical creeps (birefringence and strain) at a stress of above 4000 psi.[5] It follows von Mises' yield criterion with negligible error.[6] The material chosen for this investigation was manufactured by the General Electric Company and marketed under the trade name LEXAN. It is readily available in sheets, blocks, or extrusions.

MATERIAL CALIBRATION

A sheet of LEXAN of 0.12 in thickness was annealed at 300°F. Tensile calibration specimens were machined. Calibration tests were carried out at a temperature of 73° ± 3°F and a relative humidity of 35% ± 5%. (Photoplastic experiments are both temperature and relative humidity sensitive.) Tensile load was applied by means of dead weights. The gage length was 1.5 inches. A travelling telemicroscope was used to read the gage length under load. The strain was then calculated. Birefringence was determined by means of Senarmont's principle of compensation with a collimated monochromatic light source (5461 Å). During the calibration, Luder's lines have been observed confirming that the material follows von Mises' yield criterion.

[5]Gurtman, G. A., Jenkins, W. C., and Tung, T. K., "Characterization of a Birefringent Material for Use in Photoelasto-plasticity," Douglas Report SM-47796, Missile and Space Systems Division, Douglas Aircraft Company, January 1965.

[6]Whitfield, J. K. and Smith, C. W., "Characterization Studies of a Potential Photoelastoplastic Material," EXPERIMENTAL MECHANICS, Vol. 12, No. 2, pp. 67-72, February 1972.

Figures 1 and 2 show the fringe versus time and strain versus time curves at constant stress, respectively. It can be seen that the material creeps both optically and mechanically at a stress of above 4000 psi, confirming the previous findings. It can also be seen that the creep stabilizes after a time interval of 240 minutes. Consequently, model tests were made at the same temperature and relative humidity as were the calibration. Also, all data was taken at 240 minutes after loading.

The uniaxial stress-fringe and stress-strain curves for 240 minutes after loading were constructed from Figures 1 and 2 and shown in Figures 3 and 4. These curves show that this material has an elastic fringe value of 36 psi per inch, elastic modulus of 3.25×10^5 psi, and a proportional limit of approximately 6200 psi.

In general, calibration of stress-fringe relation must be made under two- as well as three-dimensional states of stress. However, the purpose of the present investigation was to determine the boundary stress at the fillet. Remembering that in a two-dimensional problem, there exists only one principal stress at the free boundary and the other principal stress is identically zero. Hence, a one-dimensional calibration is sufficient for the present investigation.

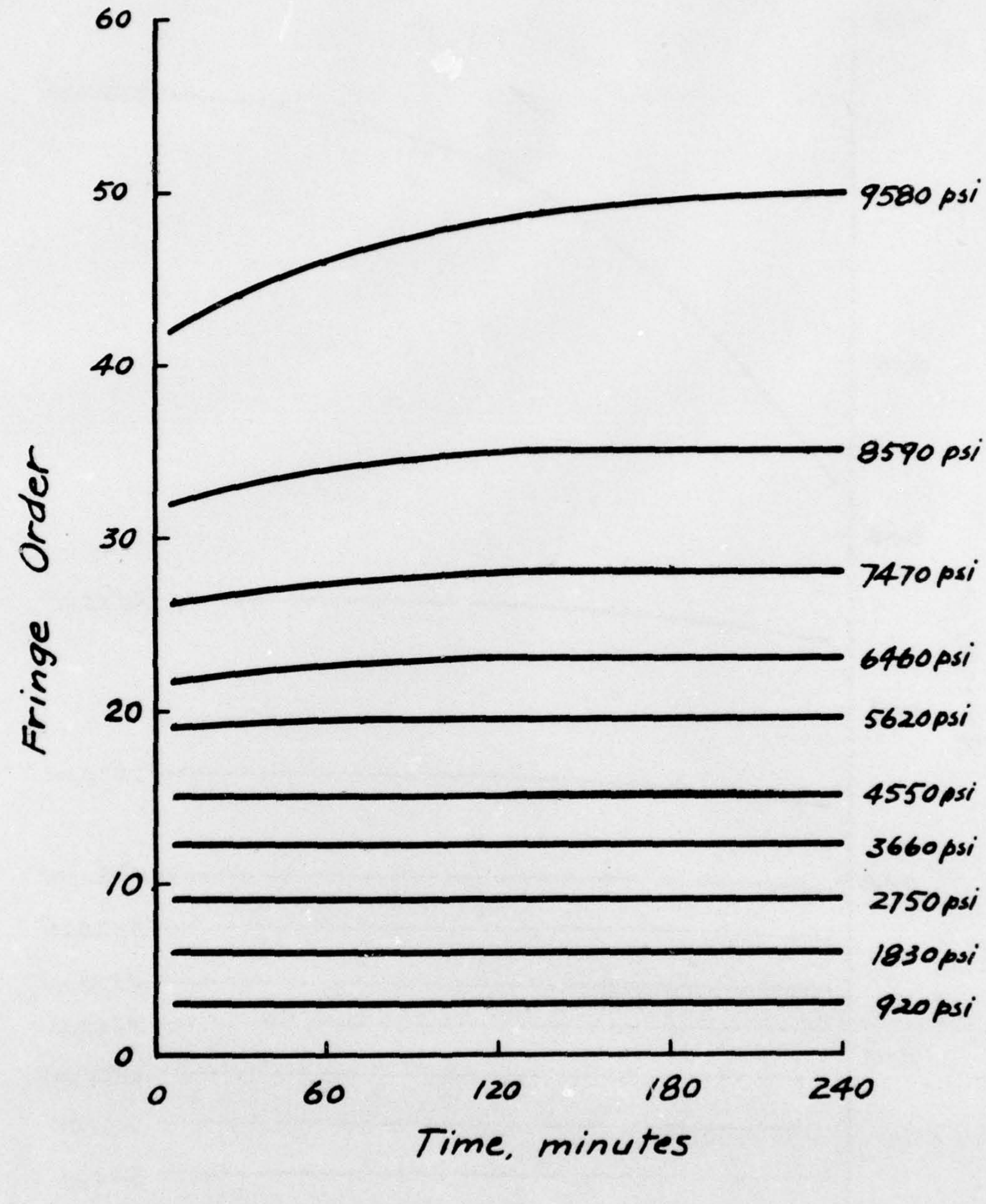


Figure 1. Birefringence at Constant Stress for LEXAN

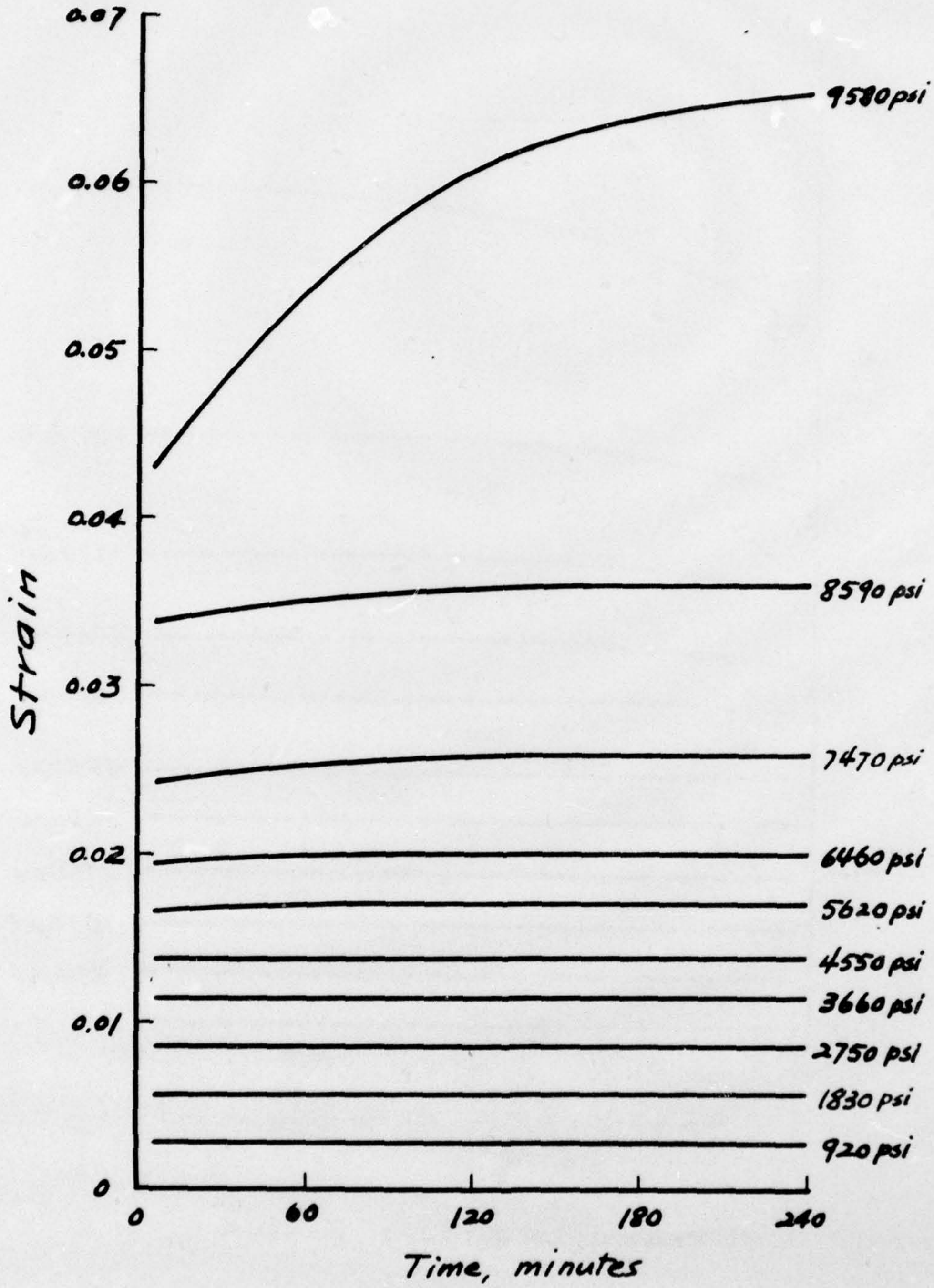


Figure 2. Strain at Constant Stress for LEXAN

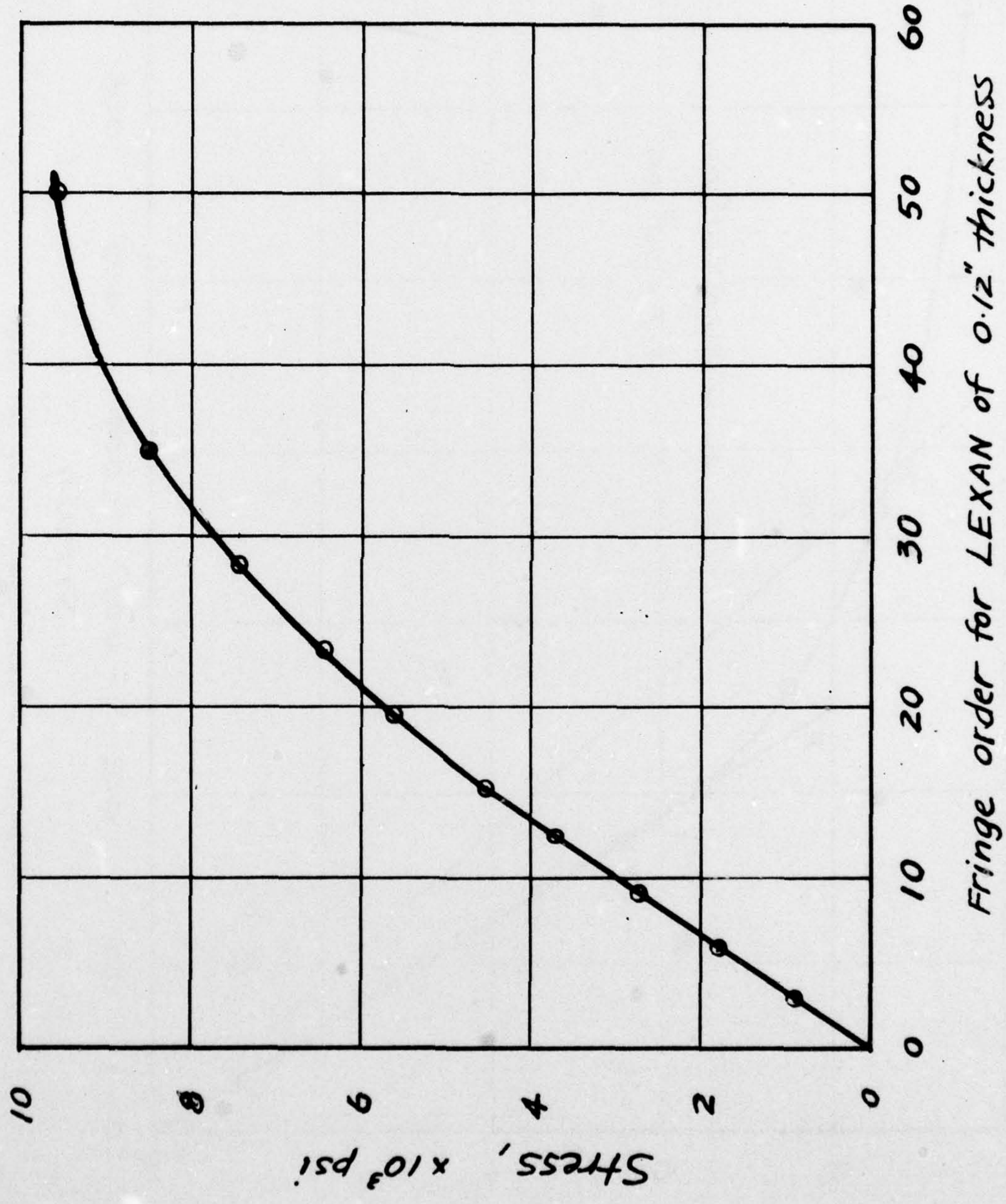


Figure 3. Stress-Fringe Curve for LEXAN

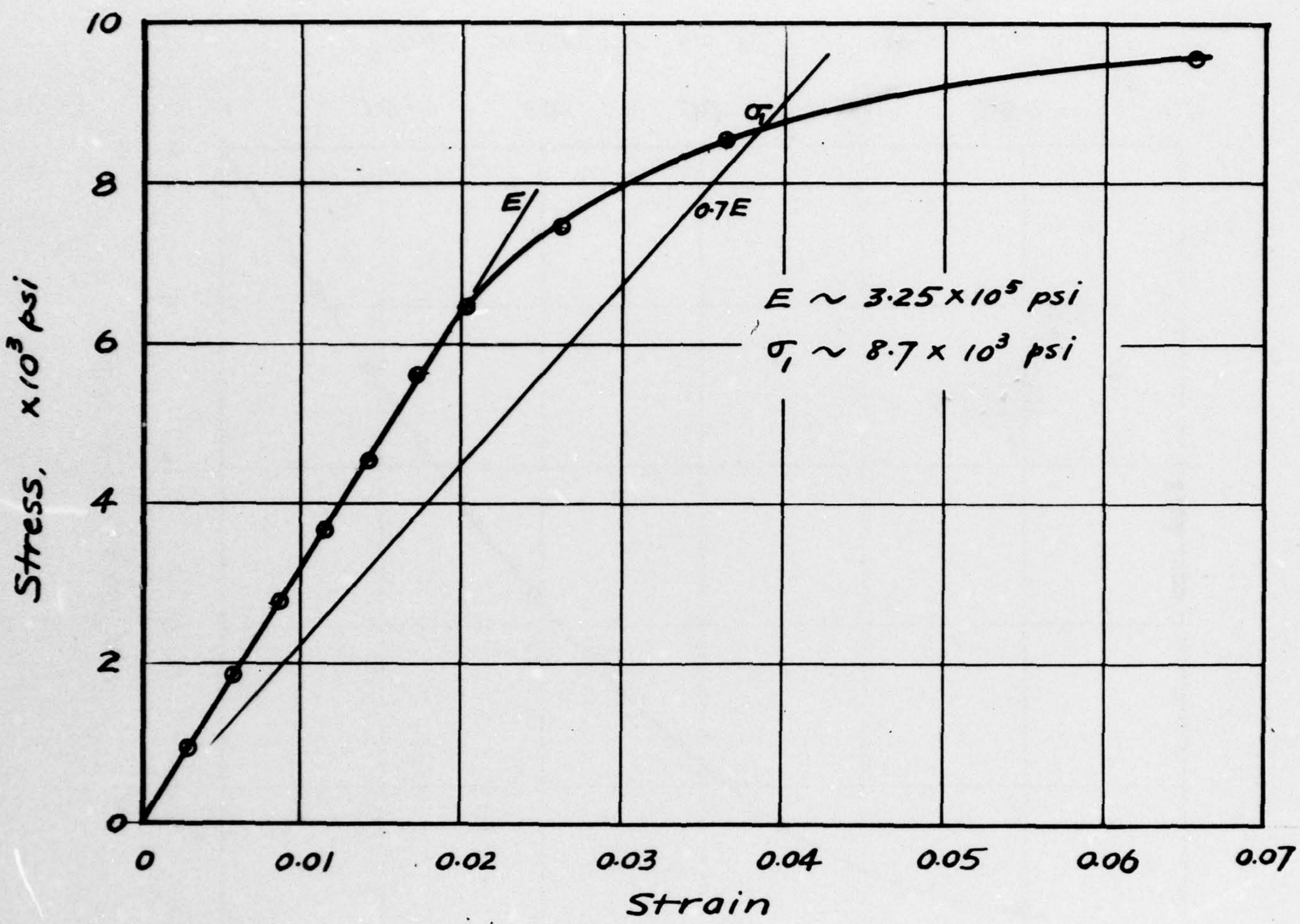


Figure 4. Stress-Strain Curve for LEXAN

NON-DIMENSIONAL STRESS-STRAIN CURVE

In 1943, a non-dimensional equation which described adequately the stress-strain behavior for most materials was published. It has the following form[7]

$$\frac{E\varepsilon}{\sigma_1} = \frac{\sigma}{\sigma_1} + \frac{3}{7}\left(\frac{\sigma}{\sigma_1}\right)^n \qquad (1)$$

where E = elastic modulus

ε = strain

σ = stress

σ_1 = secant yield strength, equal to the ordinate of the intersection with the stress-strain curve of a line through the origin having a slope equal to 0.7 E.

n = a parameter

Materials having similar stress-strain curves are characterized by the above equation with the same value of n.

From Figure 4, σ_1 = 8700 psi. Figure 5 shows the similarity of the stress-strain behavior of any material which can be characterized by the Ramberg-Osgood equation of n = 11.5 with LEXAN at 73° ± 3°F and 35% ± 5% relative humidity and 240 minutes after loading. It is possible to change the shape of the stress strain curve of LEXAN in order

[7]Ramberg, W. and Osgood, W. R., "Description of Stress-Strain Curves by Three Parameters," National Advisory Committee for Aeronautics, Technical Note No. 902, 1943.

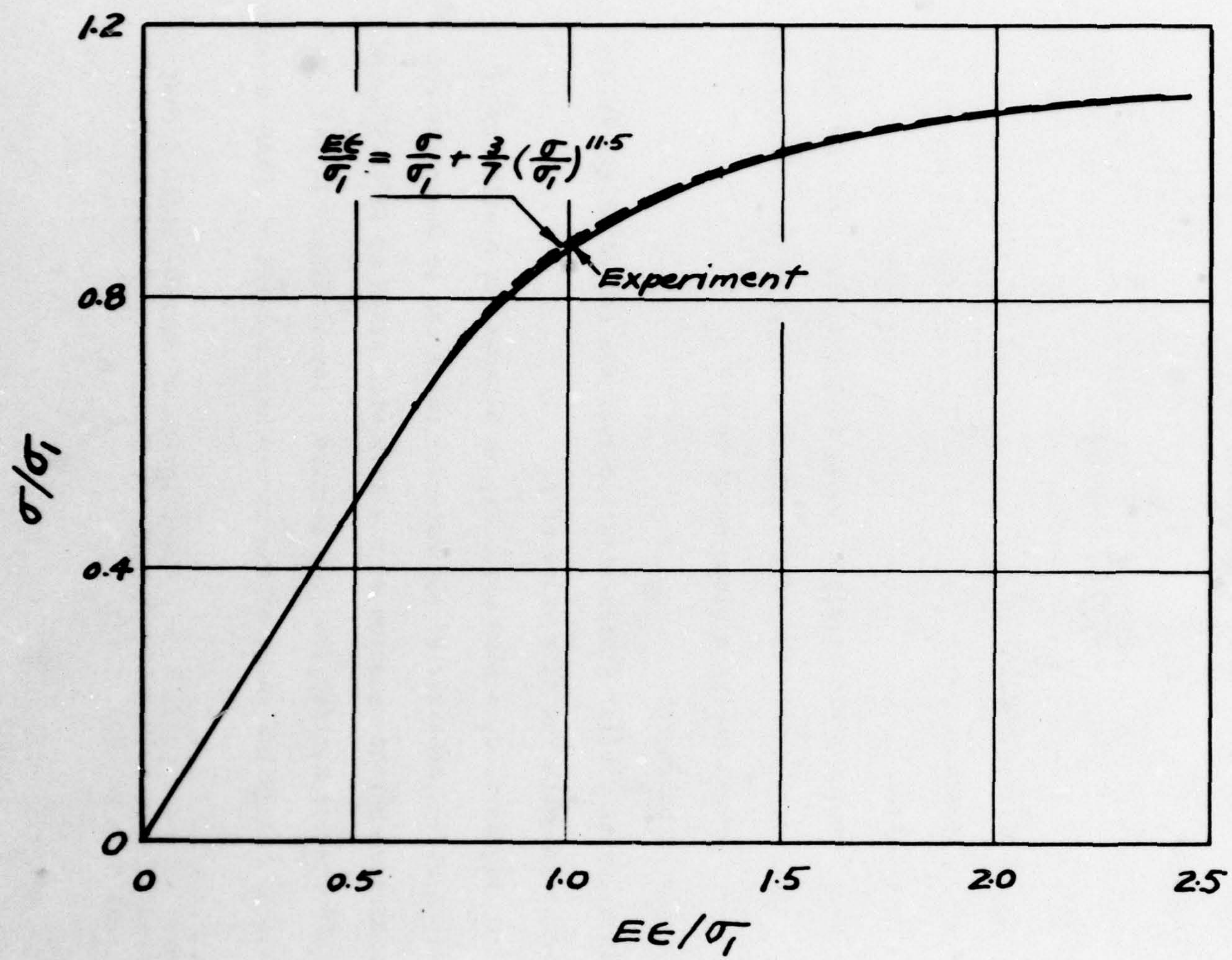


Figure 5. Comparison of Non-Dimensional Stress-Strain Curve of LEXAN with Ramberg-Osgood Equation of n = 11.5.

to make it correspond more closely to that of a particular material. This can be accomplished by varying the temperature and the relative humidity.

MODEL AND LOADING

A full scale, two-dimensional model of the meridian section of a breech ring was made of 0.12 in thick LEXAN plate, as shown in Figure 6. The block was made of aluminum. In order to minimize any effect of material nonhomogeneity, the ring was cut closely to the calibration specimens and its line of loading was parallel with that of the calibration specimens. The top of the ring was fixed. The load was applied through a pin at the top of the block by means of dead weights. Guide plates were added to prevent buckling.

MAXIMUM FILLET STRESS AT ELASTIC STATE

In order to find the maximum fillet stress at elastic state, the fringe order at the fillet was closely watched during loading. The loads corresponding to the first four integral fringes were recorded, Table 1. The incremental load required to raise one fringe order was found and averaged to give a value of 27 pounds tension per fringe, which also corresponds to a fillet stress of 300 psi per 27 pounds of load.

MAXIMUM FILLET STRESS AT PLASTIC STATE

After the elastic stress was determined, the model was loaded to 1144 pounds and held for an interval of 240 minutes. During this interval, the maximum fringe order was recorded intermittently. At the end of 240 minutes, the maximum fringe at the fillet had an order of 43

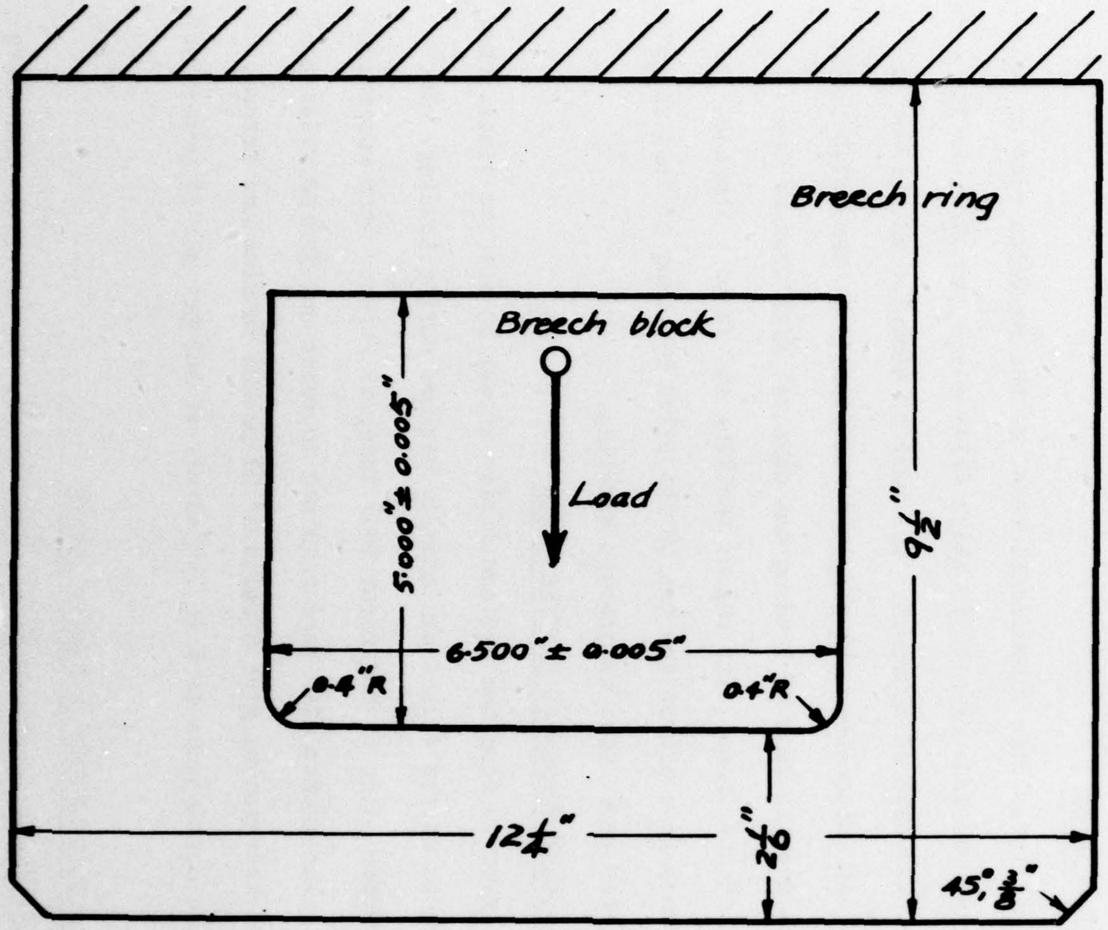


Figure 6. Sketch of the Model

TABLE 1. FILLET FRINGE ORDER

Fringe Order	Load, pound	Remarks
1	23	Elastic
2	51	
3	78	
4	104	
43	1144	Elastoplastic

which corresponds to a stress of 9300 psi. Also, the gap between the block and the ring under the full load was measured and shown in Figure 7.

PERCENTAGE OF OVERLOADING

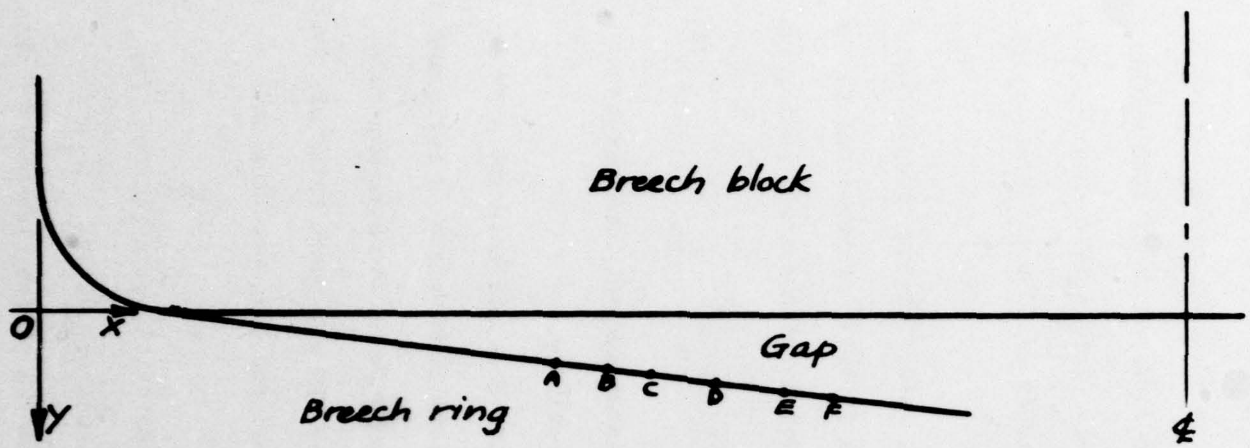
From the information that 300 psi is produced at the fillet from every 27 pounds of load, it can be shown that 558 pounds of load will put the fillet stress at the proportional limit of 6200 psi. Hence, a full load of 1144 pounds represents $\frac{1144 - 558}{558} \times 100\% = 105\%$ overloading based on proportional limit load.

Percentage of overloading based on secant yield strength of 8700 psi has not been calculated. In order to carry out this calculation, the load which would produce a fillet stress of 8700 psi had to be found. Several tests would have been necessary with each requiring a new specimen. This would be time-consuming and expensive.

CALCULATION OF RESIDUAL STRESS[8]

Although the non-linear stress-optic law is calibrated only for loading it is possible to determine the residual stress when unloading takes place. This can be done without knowing the stress-optic law for unloading, provided we make the usual assumption that unloading is inherently an elastic process.

[8] Thomson, R. A. and Frocht, M. M., "Further Work on Plane Elastoplastic Stress Distributions," Proceedings International Symposium of Photo-Elasticity, pp. 185-193, 1961.



	A	B	C	D	E	F
X	1.475"	1.625"	1.745"	1.925"	2.125"	2.255"
Y	0.0005"	0.0015"	0.002"	0.003"	0.004"	0.005"

Figure 7. Gap Under Full Load

In order to calculate the residual stress resulting from unloading, it is necessary to know the stress under the full load (9300 psi at 1144 pounds of load) and the elastic stress (300 psi per 27 pounds of load). A complete elastic unloading from 1144 pounds of load would produce a stress of $\frac{1144}{27} \times 300 = 12700$ psi. Subtractive superposition of these two values gives the residual stress of 3400 psi compression.

TRANSITION TO PROTOTYPE

In a two-dimensional problem, the elastic stresses, except those in the immediate vicinity of contact, are directly proportional to the loads and inversely proportional to the square of the scale ratio, i.e.

$$\frac{\sigma_p}{\sigma_m} \quad \frac{(P_p)}{(P_m)} \frac{(L_m)^2}{(L_p)} \tag{2}$$

where P is the load and L is a characteristic length. Subscripts m and p refer to model and prototype, respectively.

The transition of photoplastic results does not pose any difficulties. Among the three additional conditions, the Poisson's ratio and law of yielding have been satisfied. The shape of the stress-strain curve can be adjusted such that both prototype and model materials are represented by the Ramberg-Osgood equation, eq. (1), with the same parameter n.

As an example, consider a prototype material satisfying eq. (1) with $n = 11.5$ and having a proportional limit of 100 ksi. In a two-dimensional, full scale, meridian section of a breech ring made of this material, it would require a load of 9000 pounds ($100 \times 10^3 \times 27/300 = 9000$; 300 psi per 27 pounds of load) to bring the stress at the lower

fillet of the ring to the proportional limit. In order to produce an overloading of 105% with respect to the proportional limit stress, i.e., a stress of (1 + 1.05) x 100 x 10^3 = 205 ksi at the lower fillet, it would require a load of 25,200 pounds (1144 x 205 x 10^3/9300 = 25,200, eq. (2), L_m/L_p = 1). A complete elastic unloading from 25,200 pounds would produce a stress of 252 x 10^2 x 300/27 = 280 ksi. Subtractive superposition of 205 x 10^3 and 280 x 10^3 gives a residual stress of 75 ksi compression.

CONCLUSIONS AND FUTURE WORK

A photoelastoplastic investigation has been conducted to determine the maximum stress at the lower fillet of an overloaded, two-dimensional polycarbonate model of a particular breech ring section. The residual stress at the fillet after unloading was found by making the usual assumption that unloading is an elastic process. The photoplasticity results presented in this report are experimental results and, consequently, can be used to verify any analytical approach to computing residual stresses due to overstressing.

As stated earlier, at least seven conditions must be satisfied in the transition of elastoplastic data from model to prototype. They are: (a) equilibrium, (b) compatibility, (c) boundary value, (d) similarity of geometry and loading, (e) same value of Poisson's ratio, (f) same law of yielding, and (g) same shape of stress-strain curves. In a good experiment, the first three conditions will be automatically satisfied. The fourth condition can be met by proper design of the specimen and the loading. The Poisson's ratio and law of yielding are known for the

polycarbonate material used. Experimental data using the polycarbonate material is transferable to any other material having the same value of Poisson's ratio and following the same law of yielding. The last condition, the shape of stress-strain curves is represented by a parameter in the Ramberg-Osgood equation. It is possible to change the shape of stress-strain curve of the polycarbonate in order to make it correspond more closeiy to that of a particular prototype material. One way of doing this is to vary the temperature and the relative humidity of the laboratory where the experiments are conducted. Unfortunately, facilities at this laboratory do not provide for this kind of adjustment.

It is proposed for future work to determine the stresses in a scaled-down model of the meridian section of a breech ring made of the actual prototype material. Birefringent coatings and reflected light polanscope can be used to determine the elastic as well as elastoplastic states of stresses on the surface of this model. Residual stresses can then be calculated. The results could provide another evidence of the reliability of photoelastoplastic stress analysis. In addition,other geometries can be investigated using the polycarbonate material to determine residual stresses as a function of overloading.

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